



Designation: D6873/D6873M – 08

Standard Practice for Bearing Fatigue Response of Polymer Matrix Composite Laminates¹

This standard is issued under the fixed designation D6873/D6873M; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reappraisal. A superscript epsilon (ϵ) indicates an editorial change since the last revision or reappraisal.

1. Scope

1.1 This practice provides instructions for modifying static bearing test methods to determine the fatigue behavior of composite materials subjected to cyclic bearing forces. The composite material forms are limited to continuous-fiber reinforced polymer matrix composites in which the laminate is both symmetric and balanced with respect to the test direction. The range of acceptable test laminates and thicknesses are described in 8.2.

1.2 This practice supplements Test Method D5961/D5961M with provisions for testing specimens under cyclic loading. Several important test specimen parameters (for example, fastener selection, fastener installation method, and fatigue force/stress ratio) are not mandated by this practice; however, repeatable results require that these parameters be specified and reported.

1.3 This practice is limited to test specimens subjected to constant amplitude uniaxial loading, where the machine is controlled so that the test specimen is subjected to repetitive constant amplitude force (stress) cycles. Either engineering stress or applied force may be used as a constant amplitude fatigue variable. The repetitive loadings may be tensile, compressive, or reversed, depending upon the test specimen and procedure utilized.

1.4 The values stated in either SI units or inch-pound units are to be regarded separately as standard. Within the text the inch-pound units are shown in brackets. The values stated in each system are not exact equivalents; therefore, each system must be used independently of the other. Combining values from the two systems may result in nonconformance with the standard.

1.5 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate*

appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.

2. Referenced Documents

2.1 ASTM Standards:²

- D883 Terminology Relating to Plastics
- D3878 Terminology for Composite Materials
- D5229/D5229M Test Method for Moisture Absorption Properties and Equilibrium Conditioning of Polymer Matrix Composite Materials
- D5961/D5961M Test Method for Bearing Response of Polymer Matrix Composite Laminates
- E4 Practices for Force Verification of Testing Machines
- E6 Terminology Relating to Methods of Mechanical Testing
- E122 Practice for Calculating Sample Size to Estimate, With Specified Precision, the Average for a Characteristic of a Lot or Process
- E177 Practice for Use of the Terms Precision and Bias in ASTM Test Methods
- E456 Terminology Relating to Quality and Statistics
- E467 Practice for Verification of Constant Amplitude Dynamic Forces in an Axial Fatigue Testing System
- E739 Practice for Statistical Analysis of Linear or Linearized Stress-Life ($S-N$) and Strain-Life ($\epsilon-N$) Fatigue Data
- E1309 Guide for Identification of Fiber-Reinforced Polymer-Matrix Composite Materials in Databases
- E1434 Guide for Recording Mechanical Test Data of Fiber-Reinforced Composite Materials in Databases
- E1823 Terminology Relating to Fatigue and Fracture Testing

3. Terminology

3.1 *Definitions*—Terminology D3878 defines terms relating to high-modulus fibers and their composites. Terminology D883 defines terms relating to plastics. Terminology E6 defines terms relating to mechanical testing. Terminology E1823 defines terms relating to fatigue. Terminology E456 and Practice E177 define terms relating to statistics. In the event of

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² For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

a conflict between terms, Terminology **D3878** shall have precedence over the other standards.

NOTE 1—If the term represents a physical quantity, its analytical dimensions are stated immediately following the term (or letter symbol) in fundamental dimension form, using the following ASTM standard symbology for fundamental dimensions, shown within square brackets: $[M]$ for mass, $[L]$ for length, $[T]$ for time, $[\theta]$ for thermodynamic temperature, and $[nd]$ for non-dimensional quantities. Use of these symbols is restricted to analytical dimensions when used with square brackets, as the symbols may have other definitions when used without the brackets.

3.2 Definitions of Terms Specific to This Standard:

3.2.1 *bearing force, P [MLT^{-2}], n* —the total force carried by a bearing coupon.

3.2.2 *constant amplitude loading, n —in fatigue*, a loading in which all of the peak values of force (stress) are equal and all of the valley values of force (stress) are equal.

3.2.3 *fatigue loading transition, n —in the beginning of fatigue loading*, the number of cycles before the force (stress) reaches the desired peak and valley values.

3.2.4 *force (stress) ratio, R [nd], n —in fatigue loading*, the ratio of the minimum applied force (stress) to the maximum applied force (stress).

3.2.5 *frequency, f [T^{-1}], n —in fatigue loading*, the number of force (stress) cycles completed in 1 s (Hz).

3.2.6 *hole elongation, Δ [L], n —the permanent change in hole diameter in a bearing coupon caused by damage formation, equal to the difference between the hole diameter in the direction of the bearing force after a prescribed loading and the hole diameter prior to loading.*

3.2.7 *nominal value, n —a value, existing in name only, assigned to a measurable property for the purpose of convenient designation. Tolerances may be applied to a nominal value to define an acceptable range for the property.*

3.2.8 *peak, n —in fatigue loading*, the occurrence where the first derivative of the force (stress) versus time changes from positive to negative sign; the point of maximum force (stress) in constant amplitude loading.

3.2.9 *residual strength, [$ML^{-1}T^{-2}$], n —the value of force (stress) required to cause failure of a specimen under quasi-static loading conditions after the specimen is subjected to fatigue loading.*

3.2.10 *run-out, n —in fatigue*, an upper limit on the number of force cycles to be applied.

3.2.11 *spectrum loading, n —in fatigue*, a loading in which the peak values of force (stress) are not equal or the valley values of force (stress) are not equal (also known as variable amplitude loading or irregular loading).

3.2.12 *valley, n —in fatigue loading*, the occurrence where the first derivative of the force (stress) versus time changes from negative to positive sign; the point of minimum force (stress) in constant amplitude loading.

3.2.13 *wave form, n —the shape of the peak-to-peak variation of the force (stress) as a function of time.*

3.3 Symbols:

d	= fastener or pin diameter
D	= specimen hole diameter
h	= specimen thickness
k	= calculation factor used in bearing equations to distinguish single-fastener tests from double-fastener tests
L_g	= extensometer gage length
N	= number of constant amplitude cycles
P	= force carried by specimen
δ	= crosshead translation
Δ	= hole elongation
σ^{alt}	= alternating bearing stress during fatigue loading
σ^{brm}	= maximum cyclic bearing stress magnitude, given by the greater of the absolute values of σ^{max} and σ^{min}
σ^{max}	= value of stress corresponding to the peak value of force (stress) under constant amplitude loading
σ^{maxq}	= value of stress corresponding to the peak value of force (stress) under quasi-static loading for measurement of hole elongation, given by the greater of the absolute values of σ^{max} and $0.5 \times \sigma^{min}$
σ^{mean}	= mean bearing stress during fatigue loading
σ^{min}	= value of stress corresponding to the valley value of force (stress) under constant amplitude loading
σ^{minq}	= value of stress corresponding to the valley value of force (stress) under quasi-static loading for measurement of hole elongation, given by the greater of the absolute values of σ^{min} and $0.5 \times \sigma^{max}$

4. Summary of Practice

4.1 In accordance with Test Method **D5961/D5961M**, but under constant amplitude fatigue loading, perform a uniaxial test of a bearing specimen. Cycle the specimen between minimum and maximum axial forces (stresses) at a specified frequency. At selected cyclic intervals, determine the hole elongation either through direct measurement or from a force (stress) versus deformation curve obtained by quasi-statically loading the specimen through one tension-compression cycle. Determine the number of force cycles at which failure occurs, or at which a predetermined hole elongation is achieved, for a specimen subjected to a specific force (stress) ratio and bearing stress magnitude.

5. Significance and Use

5.1 This practice provides supplemental instructions for using Test Method **D5961/D5961M** to obtain bearing fatigue data for material specifications, research and development, material design allowables, and quality assurance. The primary property that results is the fatigue life of the test specimen under a specific loading and environmental condition. Replicate tests may be used to obtain a distribution of fatigue life for specific material types, laminate stacking sequences, environments, and loading conditions. Guidance in statistical analysis of fatigue data, such as determination of linearized stress life (S-N) curves, can be found in Practice **E739**.

5.2 This practice can be utilized in the study of fatigue damage in a polymer matrix composite bearing specimen. The loss in strength associated with fatigue damage may be determined by discontinuing cyclic loading to obtain the static strength using Test Method **D5961/D5961M**.

NOTE 2—This practice may be used as a guide to conduct spectrum loading. This information can be useful in the understanding of fatigue behavior of composite structures under spectrum loading conditions, but is not covered in this standard.

5.3 Factors that influence bearing fatigue response and shall therefore be reported include the following: material, methods of material fabrication, accuracy of lay-up, laminate stacking sequence and overall thickness, specimen geometry, specimen preparation (especially of the hole), fastener-hole clearance, fastener type, fastener geometry, fastener installation method, fastener torque (if appropriate), countersink depth (if appropriate), specimen conditioning, environment of testing, time at temperature, type of mating material, number of fasteners, type of support fixture, specimen alignment and gripping, test frequency, force (stress) ratio, bearing stress magnitude, void content, and volume percent reinforcement. Properties that result include the following:

5.3.1 Hole elongation versus fatigue life curves for selected bearing stress values.

5.3.2 Bearing stress versus hole elongation curves at selected cyclic intervals.

5.3.3 Bearing stress versus fatigue life curves for selected hole elongation values.

6. Interferences

6.1 *Force (Stress) Ratio*—Results are affected by the force (stress) ratio under which the tests are conducted. Specimens loaded under tension-tension or compression-compression force (stress) ratios develop hole elongation damage on one side of the fastener hole, whereas specimens loaded under tension-compression force (stress) ratios can develop damage on both sides of the fastener hole. Experience has demonstrated that reversed (tension-compression) force ratios are critical for bearing fatigue-induced hole elongation, with fully reversed tension-compression ($R = -1$) being the most critical force ratio (1-3).³

6.2 *Loading Frequency*—Results are affected by the loading frequency at which the test is conducted. High cyclic rates may induce heating due to friction within the joint, and may cause variations in specimen temperature and properties of the composite. Varying the cyclic frequency during the test is generally not recommended, as the response may be sensitive to the frequency utilized and the resultant thermal history.

6.3 *Fastener Torque/Pre-load*—Results are affected by the installed fastener pre-load (clamping pressure). Laminates can exhibit significant differences in hole elongation behavior and failure mode due to changes in fastener pre-load under both tensile and compressive loading. Experience has demonstrated that low fastener torque/clamp-up is generally critical for bearing fatigue-induced hole elongation. (1, 2, 4). It should be noted that in some instances, low torque testing of single shear specimens has proven unsuccessful due to loosening of the fastener nut/collar during fatigue loading caused by deformation of the pin/bolt.

³ The boldface numbers in parentheses refer to the list of references at the end of this standard.

6.4 *Debris Buildup*—Results are affected by the buildup of fiber-matrix debris resulting from damage associated with hole elongation. The presence of debris may mask the actual degree of hole elongation, and can increase both the friction force transfer and temperature within the specimen under fatigue loading. Experience has demonstrated that non-reversed force ratios (especially compression-compression force ratios) exhibit greater debris buildup than reversed force ratios, and that hole elongation can be most accurately determined if debris is removed prior to hole elongation measurement (1,2,4). Therefore, cleaning the specimen hole(s) prior to measurement is recommended to ensure conservatism of hole elongation data.

6.5 *Environment*—Results are affected by the environmental conditions under which the tests are conducted. Laminates tested in various environments can exhibit significant differences in both hole elongation behavior and failure mode. Experience has demonstrated that elevated temperature, humid environments are generally critical for bearing fatigue-induced hole elongation (1-4). However, critical environments must be assessed independently for each material system, stacking sequence, and torque condition tested.

6.6 *Fastener-Hole Clearance*—Bearing fatigue test results are affected by the clearance arising from the difference between hole and fastener diameters. Small changes in clearance can change the number of cycles at which hole elongation initiates, and can affect damage propagation behavior (1). For this reason, both the hole and fastener diameters must be accurately measured and recorded. A typical aerospace tolerance on fastener-hole clearance is $+75/-0 \mu\text{m}$ [$+0.003/-0.000$ in.] for structural fastener holes.

6.7 *Fastener Type/Hole Preparation*—Results are affected by the geometry and type of fastener utilized (for example, lockbolt, blind bolt) and the fastener installation procedures. Results are also affected by the hole preparation procedures.

6.8 *Method of Hole Elongation Measurement*—Results are affected by the method used to monitor hole elongation. Direct measurement permits an accurate examination of the extent of damage and elongation local to the hole surface. However, the measured elongation may not be uniform through the thickness of the laminate and may be uneven along the surface of the hole. Additionally, fasteners such as blind bolts and lockbolts are not practical to remove during fatigue testing; use of such fasteners precludes direct measurement of hole elongation. Force versus deformation data provide an “average” through-thickness measurement of hole elongation, as well as an indication of joint stiffness degradation due to damage formation. However, the accuracy of such measurements is affected by factors such as strain indicator accuracy, signal noise and slippage, grip slippage (for crosshead deflection data), friction within the joint specimen, fastener deformation, bearing deformation of load plates, and so forth.

6.9 *Reuse or Replacement of Fastener(s)*—Results are affected by whether fastener(s) are reused after hole cleaning and elongation measurement, or whether they are replaced. Both techniques have been used in industry, with reuse being the more common practice. Reuse requires less hardware and

ensures a constant fastener diameter (and fastener-hole clearance) is maintained. The removal of thread lubricant during repeated torquing can decrease preload for a given torque level; as lower preload produces more hole elongation, reuse should produce conservative results. Also, fastener degradation is part of the fatigue process, and replacement could be considered non-conservative. However, if the fastener(s) deforms during test, reuse requires that it be replaced in the same “deformed” position as it was prior to removal. Also, replacement ensures that consistent torque and preload levels are used throughout the test. The technique used during fastener re-installation (reuse or replacement) shall be recorded. It is recommended to vary hole inspection intervals to aid in assessing whether fastener removal and reinstallation affects hole elongation behavior.

6.10 *Other*—Additional sources of potential data scatter are documented in Test Method **D5961/D5961M**.

7. Apparatus

7.1 *General Apparatus*—General apparatus shall be in accordance with Test Method **D5961/D5961M**. The micrometer or gage used shall be capable of determining the hole and fastener diameters to $\pm 8 \mu\text{m}$ [$\pm 0.0003 \text{ in.}$].

7.2 *Testing Machine*—In addition to the requirements described in Test Method **D5961/D5961M**, the testing machine shall be in conformance with Practice **E467** and shall satisfy the following requirements:

7.2.1 *Drive Mechanism and Controller*—The velocity of the movable head shall be capable of being regulated under cyclic force (stress) conditions. The drive mechanism and controller shall be capable of imparting a continuous sinusoidal loading wave form to the specimen. It is important to minimize drift of the fatigue loading away from the maximum and minimum values. Achieving such accuracy is critical in the development of reliable fatigue life data since small errors in loading may result in significant errors in fatigue life. It is recommended that the test controller be equipped with a Test Amplitude controller, capable of monitoring the fatigue forces at least once every three cycles.

7.2.2 *Force Indicator*—The force indicator shall be in compliance with Practice **E4**. The fatigue rating of the force indicator shall exceed the forces at which testing will take place. Additionally, this practice recommends compliance with Practice **E467** for the development of a system dynamic conversion for the verification of specimen forces to within 1 % of true forces.

7.2.3 *Grips*—The grips shall have sufficient fatigue rating for forces at which testing will take place.

7.3 *Support Fixture*—If compressive forces are applied, either during fatigue loading or during quasi-static loading to determine hole elongation, a support fixture shall be used to stabilize the specimen. The support fixture shall be in accordance with that described in Test Method **D5961/D5961M** Procedure B.

7.4 *Thermocouple and Temperature Recording Devices*, capable of reading specimen temperature to $\pm 0.5^\circ\text{C}$ [$\pm 1.0^\circ\text{F}$].

8. Sampling and Test Specimens

8.1 *Sampling*—For statistically significant data, the procedures outlined in Practice **E122** should be consulted. From the number of tests selected a statistically significant distribution of data should be obtained for a given material, stacking sequence, environment, and loading condition.

8.1.1 *Sample Size for S-N Curve*—The recommended minimum number of specimens in the development of S-N data is described in **Table 1**. A minimum of three different force (stress) levels is recommended in development of S-N data. For additional procedures consult Practice **E739**.

8.2 *Geometry*—In addition to the requirements described in Test Method **D5961/D5961M**, the specimen geometry shall satisfy the following requirements:

8.2.1 *Stacking Sequence*—The stacking sequence should be evaluated for free edge effects to minimize the likelihood of edge delamination initiation.

8.2.2 *Specimen Configuration*—The test specimen configuration shall be in accordance with Test Method **D5961/D5961M** with the following restrictions:

8.2.2.1 *Tensile Loadings Only*—Both Procedure A (double shear) and Procedure B (single shear) configurations may be utilized. For Procedure B, both the single fastener joint and the double fastener joint geometries may be utilized. If the support fixture is used, the length of each specimen half and doubler must be adjusted to accommodate loading with the fixture. Direct measurement of hole diameter(s) is required to determine hole elongation.

8.2.2.2 *Compressive Loadings Applied*—The Procedure B (single shear) configuration must be utilized. Both the single fastener joint and the double fastener joint geometries may be utilized. The length of each specimen half and doubler must be adjusted to accommodate loading with the support fixture. Hole elongation may be determined through either direct measurement or quasi-static loadings.

8.2.3 *Adhesive*—For specimens with bonded doublers, the adhesive should have sufficient durability as to withstand fatigue loading for the duration of the test.

8.3 *Specimen Preparation*—Specimens shall be prepared in accordance with Test Method **D5961/D5961M**. Special care should be taken to ensure that specimen edges are sufficiently free of obvious flaws as determined by visual inspection. Such flaws may lead to premature failure due to edge delamination.

9. Calibration

9.1 The accuracy of all measuring equipment shall have certified calibrations that are current at the time of use of the equipment.

TABLE 1 Number of Specimens Required for Each S-N Curve

Type of Test	Minimum Number of Test Specimens
Preliminary and exploratory	6
Research and development testing	12
Design allowables data	24
Reliability data	24